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16mm film: image steadiness in television presentation

Part 2: causes of unsteadiness

No. 1971/29

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

16 mm FILM: IMAGE STEADINESS IN TELEVISION PRESENTATION
Part 2: Causes of Unsteadiness

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Part 2: Causes of Unsteadiness

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August 1971

Research Department Report No. **1971/29**
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16 mm FILM: IMAGE STEADINESS IN TELEVISION PRESENTATION

Part 2: Causes of Unsteadiness

Summary

The steadiness of pictures derived from film and presented by television is very often unsatisfactory. The causes of this unsteadiness have been determined so that the contributions from each part of the system are known. Suggestions are made as to ways in which the present performance could be improved.

1. Introduction

The greatly increased use of 16 mm rather than 35 mm film for television primarily results from the necessity to make economies in the cost of all film operations. The economy lies not only in the lower cost of the film material and processing, but also in the smaller size and lighter equipment which increases the versatility and usefulness of film cameras and reduces the size of film crew.

At one time, 35 mm film was always used for features, prestige productions and for telecine inserts into electronic camera productions but 16 mm film is now very widely used for all purposes.

The picture quality of 16 mm positive colour prints is potentially inferior to 35 mm prints in respect of resolution,[1] grain-visibility and steadiness, and this can be attributed to the fact that the picture area is only about one sixth that of 35 mm film. This report discusses only the problem of image steadiness; this cannot reasonably be considered to be the major failing of 16 mm film but the general problem of achieving adequate image steadiness is one which needs attention, particularly if film inserts into sequences made using electronic cameras are ever to be entirely satisfactory.

The requirements for image steadiness have already been described[2,3] in terms of the EBU Impairment Scale shown in Table 1. It has been shown that for a given degree of unsteadiness in terms of percentage picture height, the annoyance value is dependent on the frequency of the disturbance, high-frequency disturbances being more annoying than low-frequency disturbances.

TABLE 1

EBU Impairment Scale

Grade	
1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

It has also been shown that it is possible to derive a 'weighted' value for unsteadiness of different frequencies so that a direct comparison of the subjective steadiness of images with differing characteristics can be made (where appropriate this 'weighted' steadiness figure will be used throughout this report). The sources of image steadiness are numerous and will be discussed individually as far as possible. Summarising, they are as follows:

- The film sprocket-hole positioning accuracy of the camera mechanism
- Perforation accuracy of the negative stock
- Perforation accuracy of the positive print stock
- The relative positioning of positive and negative stock in the printer
- The film sprocket-hole positioning accuracy of the telecine mechanism
- Edge-guiding accuracy

Further unsteadiness results if an intermediate process is required as there will be one or two additional sets of printer and perforation errors.

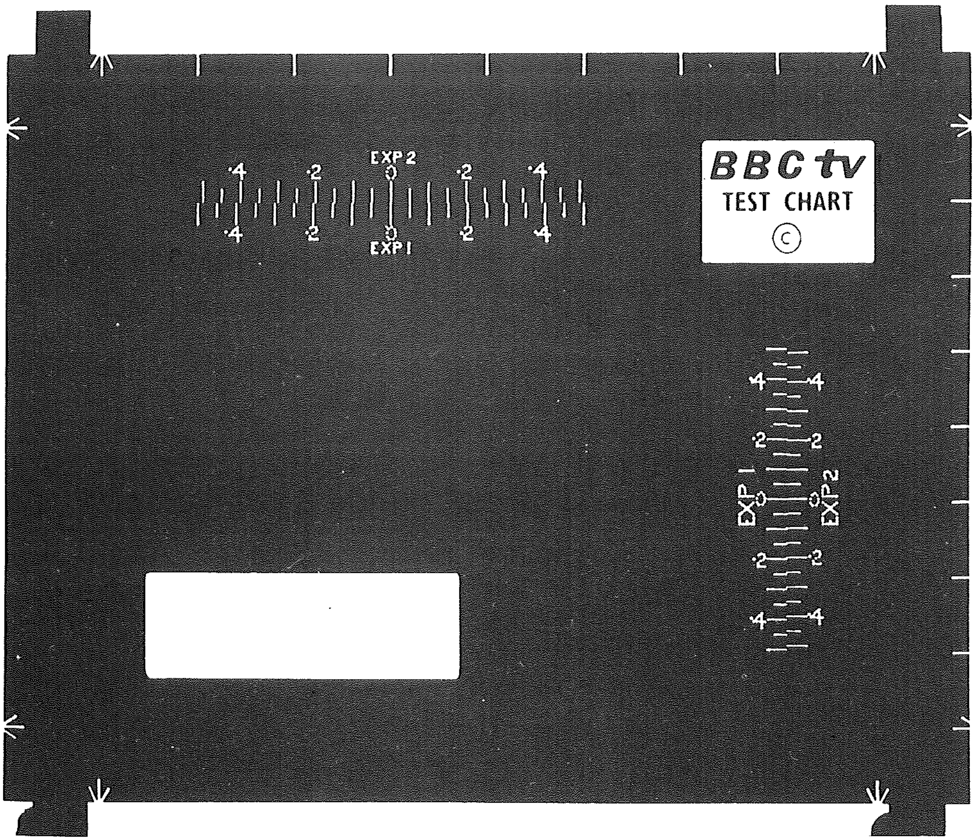


Fig. 1 - Camera steadiness test chart

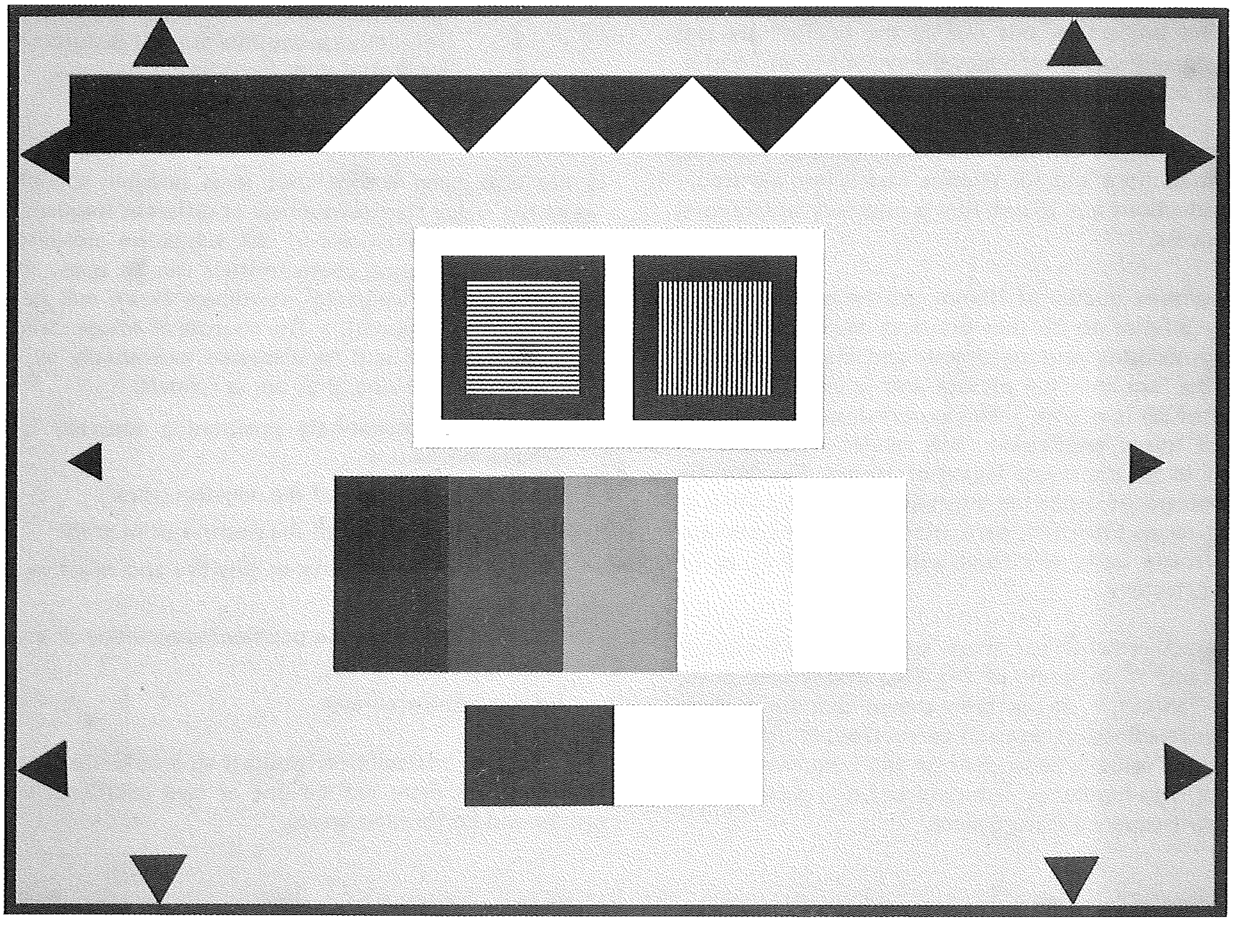


Fig. 2 - Steadiness recording chart

2. Methods of measurement

2.1. Film camera

In order to check film camera steadiness, a double run exposure of a Vernier test chart was made.[4,5]

The test chart, shown in Fig. 1, was designed to detect clearly weave or hop (horizontal or vertical unsteadiness) of 0·1% picture height or width. The chart contains two sets of Vernier scales, the horizontal set is used for weave measurement and the vertical set for hop measurement. Each Vernier set consists of two scales indicating relative movement of the two scales of 0·105% picture height or width per division. The camera mechanism is tested by exposing the chart with the 'Exp 2' scales obscured. The film is then re-wound and placed in the camera for a second exposure with the 'Exp 1' scales obscured. Relative movement of the scales reproduced on the film negative is a measurement of lack of precision in location of the film in the camera gate and is independent of the perforation accuracy of the film, provided that the film dimensions are such that the mechanism of the camera can operate as intended.

2.2. Perforation accuracy of the negative stock

The film stock to be tested was placed in a high-precision camera (in this case a rostrum camera) of measured steadiness and the chart shown in Fig. 2 was filmed. The method by which the position of each reproduced film frame can then be determined has been described in detail elsewhere.[3]

The minimum number of sources of unsteadiness that can be present is three, i.e. the original camera, the negative or reversal original film and the telecine. The film camera contribution can be established from the measurements described in Section 2.1 and can be stated in the form that the contribution from this source is not greater than x% picture height. The contribution of the continuous motion telecine used for the measurement was substantially eliminated by using a loop of film together with the method of averaging the errors which is described in Section 5.4 of Part 1 of this report.[3]

This averaging technique not only eliminated any alternate frame component from the telecine and also any 12 frame component which might possibly be present due to the presence of 12 teeth on each sprocket wheel, but it also reduced any random unsteadiness and measurement errors by averaging 12 completely independent measurements. This approach can only be feasible if a computer is used to perform the analysis since the analysis of each film loop involves 3,612 measurements. With the effect on measurements of telecine unsteadiness thus reduced to a very small value, it may then be used as a measuring instrument enabling the steadiness of the negative to be determined. This measurement thus represents the contribution to unsteadiness from the camera and the film stock taken together. If the camera unsteadiness is known from the double exposure test, this may be subtracted from the measured steadiness to determine the perforation accuracy of the film stock.

2.3. The telecine

In the previous Section, 2.2, a method has been mentioned for averaging the performance of the telecine so that it becomes relatively unimportant in making other measurements. The performance of the telecine can therefore be determined by subtracting from individual measurements, made on every frame of each of the twelve runs, the average measurement for each frame determined from the twelve runs. This difference is the contribution by the telecine. By comparing these twelve measurements, the nature of the telecine unsteadiness can be determined. If there is no correlation it can be assumed that the unsteadiness is purely random. If a periodic disturbance is found in all twelve measurements and this is also correlated between the measurements, then the measurements can be combined to increase the accuracy and an analysis made of the periodic components.

This technique may be applied to any type of telecine machine provided that the loop length is adjusted to suit the number of sprocket teeth or gear teeth in the traction mechanism that may give rise to periodic film positioning errors in the picture gate.

If the likely periodic errors cannot be anticipated, then a Fourier analysis of the unsteadiness recorded for a single run could be made, and any obvious periodic components noted and used to determine the most suitable loop length.

2.4. Printer and positive stock

No attempt has been made specifically to measure the printer and positive-stock characteristics separately since the positive stock is not normally double-perforated, and cannot therefore be exposed in a high precision camera.

A standard negative of known steadiness was used to make positive prints as part of routine jobs. The prints were then analysed in a 301-frame loop to minimise the effect of telecine errors in the measurement.

3. Measurement accuracy

Measurement accuracy was limited by quantising errors in the measurement apparatus, by noise on the reproduced pictures from the telecine machine and by the stability of the telecine scanning raster. In order to examine the total magnitude of these effects a section of test film was placed and held stationary in the telecine gate, and the scanning raster adjusted to produce as nearly as normal a picture as possible. A recording of the steadiness was then made.

No attempt could be made to separate errors due to quantising and to noise: only the total was determined by making the recording of steadiness measurements in the normal way. The results were as follows:

Horizontal unsteadiness, weighted r.m.s. = 0·020% picture height

Vertical unsteadiness, weighted r.m.s. = 0·013% picture height

These errors were entirely random and allowed for by direct subtraction on an r.m.s. basis when the telecine averaging technique could not be used. In most cases this technique was used, and the accuracy was therefore improved by a factor of $\sqrt{12}$ so that errors of measurement were usually small compared with the unsteadiness being measured.

4. Steadiness requirement

This is dealt with in detail in Part 1 of this report[3] in which it is shown that for a still scene to be reproduced with 'definitely perceptible but not disturbing' unsteadiness (grade 3), the weighted r.m.s. unsteadiness must not be greater than 0·035% picture height in either the vertical or horizontal direction or the vector sum of both directions.

5. Sources of unsteadiness

5.1. The camera

Camera steadiness was measured only by means of the double exposure test. In the cases of both the rostrum camera and typical high-grade professional cameras the relative movement of the Exposure 1 and Exposure 2 scales was usually undetectable, both by examination under a microscope and by optical projection.

It can be concluded that both types of camera are capable of locating a specific film frame in the same position repeatedly to an accuracy of better than ±0·05% picture height. This can be converted to an equivalent r.m.s. error, once it is known how frequently the peak error is encountered. If it can be assumed that a peak error is encountered only once in every hundred film frames,* then provided that position errors are Gaussian in distribution probability theory states that

$$\text{Equivalent r.m.s.} = \frac{\text{Peak value in 100 frames.}}{2{\cdot}58}$$

The r.m.s. unsteadiness of the camera is therefore less than 0·019% of picture height and the weighted r.m.s. value derived from this figure and the weighting curve mentioned in Section 1 is 0·017% (position errors being assumed to be Gaussian in distribution). If this were the only cause of image unsteadiness, it would not normally be visible even on still scenes.

5.2. The perforation accuracy of the negative stock

The dimensions of short-pitch double-perforated 16 mm negative stock which are recommended and recognised as a standard are stated in British Standard 4562: Part 2, 1969. These are reproduced in Fig. 3.

As far as vertical steadiness is concerned, dimensions *B* and *D* are all important. Dimension *B* is only important if the reproducing mechanism register pin or claw does not engage the same perforation with respect to the image as does the register pin in the camera. All the cameras considered have register pins in the positions shown in Fig. 4.

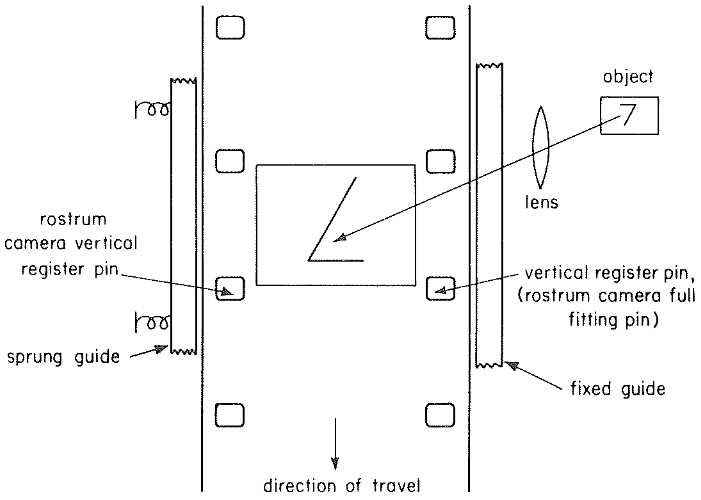
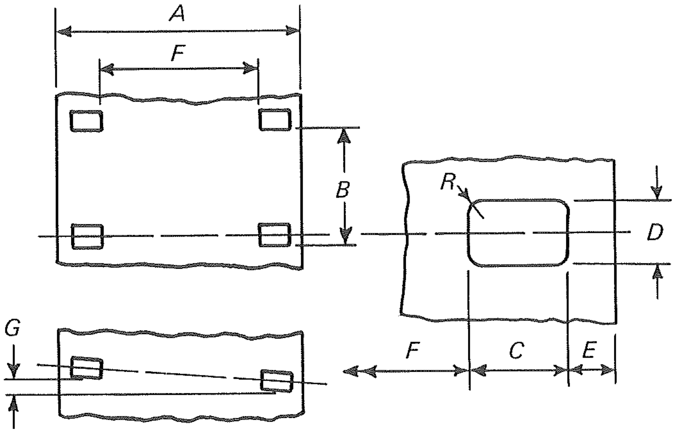

object
lens
rostrum camera vertical register pin
sprung guide
vertical register pin, (rostrum camera full fitting pin)
fixed guide
direction of travel

Fig. 4 - Camera register pin and guide location

Dimension	mm	Tolerance % Picture Height
A	15·950 ± 0·025	
B	7·605 ± 0·01	± 0·13
C	1·83 ± 0·01	± 0·13
D	1·27 ± 0·01	± 0·13
E	0·90 ± 0·05	± 0·66
F	10·490 ± 0·025	
G	0·025 max.	
R	0·250 ± 0·025	
L *	760·5 ± 0·8	± 0·105



L * represents the length of any 100 consecutive perforation intervals

Fig. 3 - Dimensions of 16 mm stock ISO type 16-2R-B

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* A period of 100 frames has been chosen since this number is large enough to ensure that it is statistically likely that any extreme dimension measured will be almost as great as that measured over a much greater number of frames. At the same time it is practical to measure this number of dimensions by relatively simple means.

If the dimension B were to vary from +0·13% to −0·13% (as permitted by the specification) of its nominal value over 100 frames in a random manner, and the telecine claw engaged one perforation away from that used by the camera register pin, then an equivalent r.m.s. unsteadiness may be calculated on the same assumption as that used in the previous section. The r.m.s. unsteadiness is therefore 0·13/2·58 or 0·05% corresponding to a weighted r.m.s. steadiness of 0·045%. In the case of the particular continuous motion telecine mechanism considered, the claw engages three perforations away from the perforation occupied by the camera register pin. Again, if the perforation errors are Gaussian in distribution, probability theory shows that the unsteadiness will be $\sqrt{3}$ times greater than if it had engaged one perforation away from that occupied by the camera register pin, and therefore a weighted r.m.s. unsteadiness of 0·078% might be anticipated. Hence, if the film exploited the tolerances permitted, pictures from an original camera negative (or reversal) film would have a visibility of vertical unsteadiness of grade 5.[3] It has been proposed by the European Broadcasting Union[6] that for 16 mm colour motion picture film for television, the tolerance on dimension B should be

$$\text{Dimension } B = \frac{\text{Measured value of dimension } L}{100} \quad \pm 0{\cdot}005 \text{ mm}$$

This represents a tolerance of ±0·066% picture height. Again, if this occurred once in 100 frames in a random manner it would give rise to pictures with a weighted vertical r.m.s. unsteadiness of 0·039% in this particular telecine and a visibility of unsteadiness of grade 3 due to perforation inaccuracy alone. It seems likely that this peak value will not be reached as often as once in 100 frames and this is confirmed by experimental observation (see Table 2) which indicates that vertical unsteadiness due to perforation inaccuracy is usually less than 0·022% weighted r.m.s. (Camera unsteadiness of 0·017% having been subtracted from the average total of 0·028%.) In order to achieve this it can be concluded that in practice a peak limit of ±0·0028 mm is not exceeded more frequently than once in 100 frames. Since this is the accuracy actually achieved this could form the basis of a new specification for short-term perforation accuracy.

It is, however, still possible that the film could have periodic perforation inaccuracy and yet be within specification. A selection of periodic perforation inaccuracies will be considered with reference to their effect on the image steadiness of camera original negative reproduced by a telecine machine pulling down three frames from the register pin position of the camera. Fig. 5 shows five different types of periodic perforation error that could occur; many others are, of course, possible. Again B is the dimension B shown in Fig. 3 and δB is the peak value of the tolerance on dimension B. The image displacement of successive frames is also shown for each type of error. The maximum image displacement that can occur is 2 n δB where n is the number-of-frames separation between the camera register pin and the telecine claw. This is shown as perforation type 1 and will produce a disturbance with a period of six frames. The maximum weighted r.m.s. value of this disturbance calculated from that permitted by the British Standards specification is 0·25% which will produce unsteadiness which is totally unacceptable (seven times the acceptable value). None of the tests have, in fact, shown any significant periodic disturbances of this type; the fact remains, however, that of two films with a given perforation accuracy well within existing specification limits, one could produce acceptable vertical steadiness while the other would be useless.

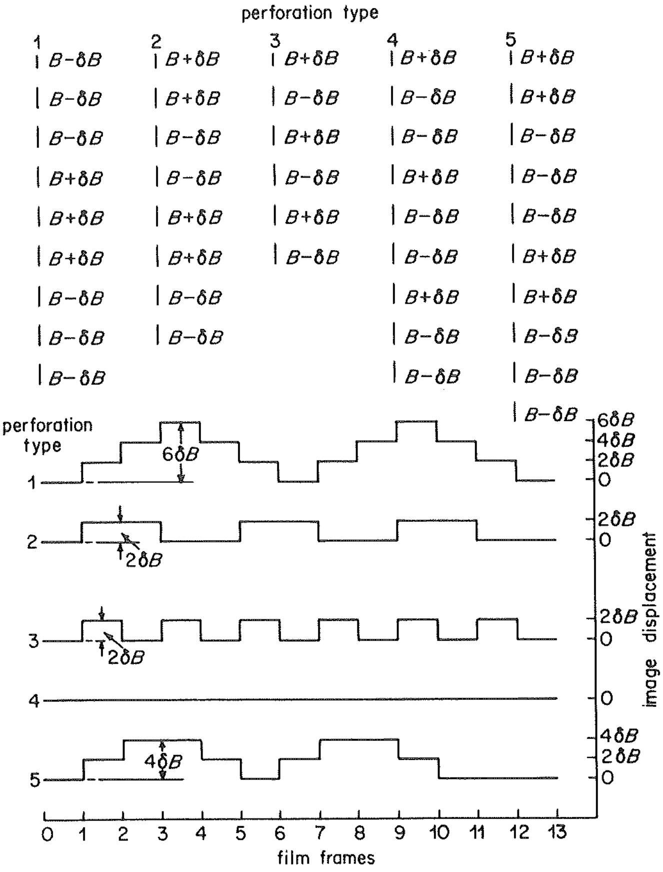

Fig. 5 - Image unsteadiness caused by periodic perforation inaccuracy

The effect of dimension D depends on the film transport and register mechanism. As far as the particular continuous-motion telecine considered here is concerned it is totally unimportant, since the film is in tension with the claw pulling against the leading edge of the perforation. In the case of a camera with a full fitting register pin of nominally 1·27 mm height, the pin cannot theoretically enter the film if D has the minimum specified dimension and it can only be assumed that the register pin occupies the mean position of the sprocket hole. If the dimension D is at its maximum limit a further error in position from frame to frame of 0·01 mm could arise. In practice this is unlikely to occur since the register pin is typically only 1·22 mm in height and the pull down claw will be adjusted so that the register pin bears on the leading edge of the sprocket hole.

As far as horizontal steadiness is concerned the dimensions E and C (Fig. 3) are most important if either the film camera or the telecine machine uses a register pin for lateral location of the film. More frequently, however, 16 mm equipment uses edge guidance by spring loading the film in the gate against an edge guide and the film perforation dimensions should be relatively unimportant. The rostrum camera, however, uses a register pin 1·83 mm wide for horizontal location, see Fig. 4, and if it can be assumed that the film frame is registered with reference to the centre of the sprocket hole, when this is of nominal or minimum size, then the tolerance of the centre of the sprocket hole, when of maximum size with reference to the edge of the film, is the tolerance on *E*, i.e. ±0·05 mm together with the tolerance on *C*, i.e. 0·01 mm. Therefore the total tolerance in this worst case is the r.m.s. sum of these tolerances, i.e. ±0·0503 mm. This represents ±0·66% picture height or 0·23% weighted r.m.s. unsteadiness if this limit occurs once in 100 frames. This degree of unsteadiness would be completely unacceptable. Table 2 shows actual measurements made of both the vertical and horizontal steadiness obtained using six batches of negative material exposed in the rostrum camera at normal speed. The telecine random contribution has been minimised by the averaging technique described earlier.

TABLE 2

Weighted R.M.S. % Steadiness of 6 Batches of Negative Exposed in Rostrum Camera

Batch	Vertical	Horizontal	Vector Sum
1	0·026	0·036	0·045
2	0·021	0·035	0·040
3	0·027	0·042	0·050
4	0·023	0·033	0·040
5	0·037	0·030	0·048
6	0·020	0·035	0·040
Average	0·028	0·035	0·044

Fourier analysis of both the vertical and horizontal unsteadiness shows that there is no predominant cyclic component and that the spectrum of each conforms closely to that of random noise. In Section 5.1 it was concluded that the maximum vertical contribution from the camera was not greater than 0·017% weighted r.m.s. It is therefore possible to say that the contribution from the perforation inaccuracy is not greater than 0·028% weighted r.m.s. and not less than 0·022% weighted r.m.s. The conclusion that can be drawn is that the film perforation accuracy of dimension *B* is usually somewhat better than the proposed EBU specification.

The average horizontal steadiness measured was 0·035% weighted r.m.s. compared with 0·23% weighted r.m.s. predicted by the British Standards specification if the tolerance was fully exploited in 100 frames. This discrepancy indicates that while a wide tolerance on long-term variations of dimension *E* may be necessary from the manufacturers' point of view it would be desirable to specify that the variation in dimension *E* over 100 frames should not exceed, for example, ±0·005 mm giving a weighted r.m.s. figure of 0·023%, if the errors were random. This figure would give a steadiness of grade 2 if the negative perforation alone was the cause of unsteadiness and dimension *C* was invariable. If dimension *C* were also permitted to have a tolerance of ±0·005 mm and the negative perforation alone was the cause of unsteadiness, the total weighted r.m.s. unsteadiness would be 0·033% (this assumes that the register pin of the camera just fits the minimum tolerance limit of the film) and pictures of steadiness of better than grade 3 would result. It is therefore suggested that the specification for dimension *E* should be

0·90 ± 0·05 mm over 100 consecutive frames

with the limitation that dimension *E* shall not vary by more than ±0·005 mm within 100 frames, also that dimension *C* should ideally be

1·83 ± 0·005 mm

This would give a total tolerance of ±0·007 mm for the horizontal positional accuracy, or ±0·092% picture height, resulting in a weighted r.m.s. unsteadiness of 0·033%.

The total horizontal and vertical steadiness resulting from film conforming to the new suggested tolerances for dimensions *B, C* and *E* is therefore

$$\sqrt{0{\cdot}022^2 + 0{\cdot}033^2} = 0{\cdot}039\% \text{ weighted r.m.s.}$$

This would give pictures of grade 3, which is only just adequate with no tolerance for the camera and telecine.

Summarising, the new proposals for the film dimensions specification which are most important to users of film for television could take the form shown in Table 3. This table could be appended to the present British Standard 4526: part 2 1969 as an addition to the present tables of dimensions which would remain unaltered except for an improvement to the tolerance on dimension *C*.

TABLE 3

Proposed Additions to Film Dimensions Sepcification

Dimension	Maximum permitted variation in 100 consecutive perforation intervals
B	± 0·003 mm
C	± 0·005 mm
E	± 0·005 mm

Even these proposals would only ensure pictures with a steadiness of grade 3 provided that no unsteadiness occurred in the camera or telecine and camera original film were used.

5.3. The total performance of camera and film

It has already been mentioned that the film dimensions should be relatively unimportant in achieving good horizontal steadiness if edge guidance is used in both the camera and the telecine machine. This will, however, only be true if the camera and telecine edge-guides are identical in their method of operation and in their position in relation to the film gate. This cannot ever be achieved in the types of camera and telecine being considered since intermittent motion of the film occurs in the camera while in the telecine the motion is continuous. In some cameras a comparatively long fixed guide is used (typically 72 mm) which embraces the area of the gate while a sprung guide operates on the other edge of the film; thus the film is located by the position of the extreme edges of the film over several frames. In the case of the particular continuous motion telecine being considered, the film is biased to one side of the gate by rollers and is located by a small roller acting on the edge of the film which is situated in line with the centre of the gate. Table 4 shows the horizontal and vertical steadiness achieved in twelve cameras of the same make using a single batch of negative stock. The measurements are the mean of twelve runs in the telecine machine so that random unsteadiness of the telecine is effectively almost removed.

TABLE 4

Weighted R.M.S. % Steadiness of Cameras Using a Single Batch of Negative Stock

Camera	Vertical	Horizontal
1	0·036	0·072
2	0·034	0·075
3	0·021	0·032
4	0·021	0·037
5	0·021	0·053
6	0·028	0·038
7	0·047	0·043
8	0·027	0·034
9	0·043	0·053
10	0·028	0·045
11	0·029	0·041
12	0·021	0·049

Comparison of these results with those shown in Table 2 for the rostrum camera shows that the vertical steadiness in most cases is not significantly worse and in some cases better.

The horizontal steadiness was very variable. In the cases of cameras 3, 4, 6, 7, 8, 10 and 11 the results were comparable with those achieved by the rostrum camera using a register pin, while cameras 1, 2, 5 and 9 were poor. A double exposure test showed detectable unsteadiness only in the case of cameras 1 and 2. A further test was conducted using a single camera of average performance but with five different batches of negative stock. The results are shown in Table 5.

Comparison with the rostrum camera results shown in Table 2 (batch numbers are not related) shows that the stock causes similar variations in both vertical and horizontal steadiness in both cameras. Comparing the results in Tables 4 and 5, it can be concluded that variations in camera performance are probably greater than variations caused by the stock. No completely satisfactory conclusion can be drawn from the measurements relating to edge guidance: all that can be said is that any one batch of film stock behaves differently in different cameras and that, in any one camera, different batches of film stock will behave differently. Both these results can partly be explained by saying that the way in which film is guided through the camera and telecine depends both on the guide adjustment of the camera and the film stock, and that the characteristics of the guide system will vary with film stock characteristics such as warp, twist, edge roughness, surface friction etc.

TABLE 5

Weighted R.M.S. % Steadiness of Different Batches of Negative Stock Exposed in One Camera

Batch	Vertical	Horizontal
1	0·025	0·035
2	0·040	0·029
3	0·027	0·044
4	0·024	0·023
5	0·028	0·032
Average	0·029	0·033

5.4. The telecine

The vertical steadiness of the continuous motion 16 mm telecine is dependent on the adjustment of the claw mechanism and the perforation pitch of the negative stock. In order to achieve continuous traction two claws are required. Two adjustments of the claw mechanism are provided to ensure that the relative positions of the film frame and the scanning raster are as nearly identical as possible during the two television field scans of the one film frame. One adjustment allows the phasing (or timing) of the two claws to be adjusted so that both claws move the film at identical speeds. If only the phasing adjustment is incorrect an identical alternate frame component of unsteadiness will be measured through both lenses of the telecine. If the velocity adjustment is incorrect different results will be obtained depending on which lens is used for the measurement.

Table 6 shows the weighted r.m.s. unsteadiness of a negative, exposed in the rostrum camera at slow speed to ensure the greatest possible steadiness, and measured in one particular twin-lens telecine. Any periodic telecine error has been removed by the averaging technique referred to in Section 2.2. This will also have reduced any random errors.

TABLE 6

Weighted R.M.S. Unsteadiness of the Negative used for Telecine Steadiness Measurements

Top lens vertical unsteadiness	0·013%
Top lens horizontal unsteadiness	0·019%
Bottom lens vertical unsteadiness	0·013%
Bottom lens horizontal unsteadiness	0·020%

The results in Table 6 can now be used to examine the unsteadiness of this particular telecine machine since they represent a close approximation to the steadiness which would be achieved if the negative film had been viewed by means of a perfect telecine machine. They therefore show the steadiness achieved by the film camera and film stock taken together.

TABLE 7

Telecine Weighted R.M.S. Unsteadiness

Top lens/ Bottom lens	Vertical/ Horizontal	Telecine Unsteadiness (+ Measurement Errors)	Telecine Unsteadiness (+ Measurement Errors) Alternate Frame Component Eliminated
		%	%
Top lens	V	0·042	0·018
	H	0·018	0·019
Bottom lens	V	0·025	0·018
	H	0·021	0·020

Table 7 shows the mean results of twelve individual measurements in which the error present in the negative for each frame (determined by the averaging technique) has been subtracted from the measurements made on each of the twelve runs. This removes the film unsteadiness, leaving the telecine unsteadiness and measurement errors. Also shown are the measured results with components of alternate frame frequency removed.

The mean telecine unsteadiness in the horizontal direction shown in Table 7 includes measurement errors. These have already been stated (see Section 3) to be equivalent to a weighted r.m.s. unsteadiness of 0·020% picture height. It can therefore be concluded that the contribution from the telecine was negligible.

Vertical unsteadiness measured through the top lens had a mean unsteadiness of 0·042% picture height (see Table 7). Fourier analysis of this unsteadiness indicated that a major contribution was an alternate frame component with no other significant periodic components. The analysis was therefore repeated with the alternate frame component eliminated from the calculation. The total vertical unsteadiness was then found to be only 0·018% picture height which is close to the measurement accuracy of 0·013% picture height, indicating that random vertical unsteadiness did not exceed 0·012% while the alternate frame component was 0·038% picture height.

Vertical unsteadiness measured through the bottom lens had a mean unsteadiness of 0·025% picture height (see Table 7). Fourier analysis again indicated that there was a significant alternate frame component and when this was eliminated the total unsteadiness dropped to 0·018% picture height. This figure is identical to that achieved through the top lens, and is an expected result since the film remains on the same claw while being scanned through both lenses. The alternate frame component in this case was 0·017% and again the maximum random unsteadiness did not exceed 0·012% picture height. These results show that this particular telecine machine had a small phase error between the claws which caused an alternate frame component of unsteadiness in the top lens. This phase error was partially compensated by a velocity error so that the unsteadiness was less when measured through the bottom lens.

It is probable that further adjustment of the telecine would allow the results on both lenses to be similar to that achieved on the bottom lens.

5.5. The total performance of camera, film and telecine

The total unsteadiness that can be expected from a directly replayed negative or reversal original exposed in a precision camera at slow speed is as shown in Tables 8 and 9. This probably represents the ultimate steadiness which can be achieved at the present time using first class mechanisms.

TABLE 8

Total Weighted R.M.S. Vertical Unsteadiness

Camera and negative	0·013%
Telecine random	0·012%
Telecine alternate frame	0·017%
Total	0·024%

TABLE 9

Total Weighted R.M.S. Horizontal Unsteadiness

Camera and negative	0·020%
Telecine random	Negligible
Telecine alternate frame	Negligible
Total	0·020%

The vector sum of both disturbances gives a total weighted r.m.s. unsteadiness result of 0·031% picture height.

This is very close to the grade 3 visibility limit[3] of 0·035% (see Section 4). In practice, using a normal high-grade camera, the total performance will be somewhat worse than this. From Table 5 the average performance which can be anticipated from an average camera/film combination in good condition is shown to be:

Vertical unsteadiness 0·029% weighted r.m.s.

Horizontal unsteadiness 0·033% weighted r.m.s.

If these values are substituted in Tables 8 and 9 the total vector sum for the camera and film and telecine becomes 0·048% weighted r.m.s., which gives a visibility of unsteadiness of grade 3½.

5.6. Printer and positive stock

In order to examine the performance of printers achieved in routine operation, a quantity of the processed negative of the steadiness chart, exposed in the rostrum camera, which was the subject of the analysis in Section 5.4, was supplied to BBC Film Department. Approximately 10 feet was attached to negative programme material and sent in the normal way to laboratories for printing. This test was spread over a period of several weeks and involved two processing laboratories. After printing, the test chart sections were removed and analysed. In all cases the prints were made on a single type of continuous contact printer, but each laboratory had several machines, thus many permutations of positive stock batch and machine were examined.

A subsequent series of tests were conducted with the co-operation of one processing laboratory in which a single batch of positive stock was used on four printers and three batches of stock were used on one printer.

All the print measurements were first Fourier analysed so that significant periodic components could be identified and the alternate frame contribution by the telecine deducted from the total measured weighted r.m.s. unsteadiness.

In order to determine the contribution to the total of the combined printer and positive stock unsteadiness, the following known average contributions to the total measured unsteadiness were deducted.

Telecine random unsteadiness (see Section 5.4)

Camera and negative unsteadiness (see Section 5.4)

Estimated measurement errors (see Section 3)

The resulting weighted r.m.s. unsteadiness is that which is contributed by the printer and positive stock. This is shown in Figs. 6 and 7. In the case of vertical steadiness see Fig. 6, it will be seen that the smallest contribution of 0·031% by the printer and positive stock was from Test 6, (Laboratory 1) and the greatest contribution 0·098% from Test 8, (Laboratory 2). In between these limits there is a reasonably even scatter of results with a mean value of 0·053%. On average, therefore, the printer and positive stock caused more vertical unsteadiness than the vector sum of horizontal and vertical unsteadiness of all the other remaining items taken together (see Section 5.5). Also shown in Fig. 6 is the 40 frame period component for each measurement. This will be referred to later.

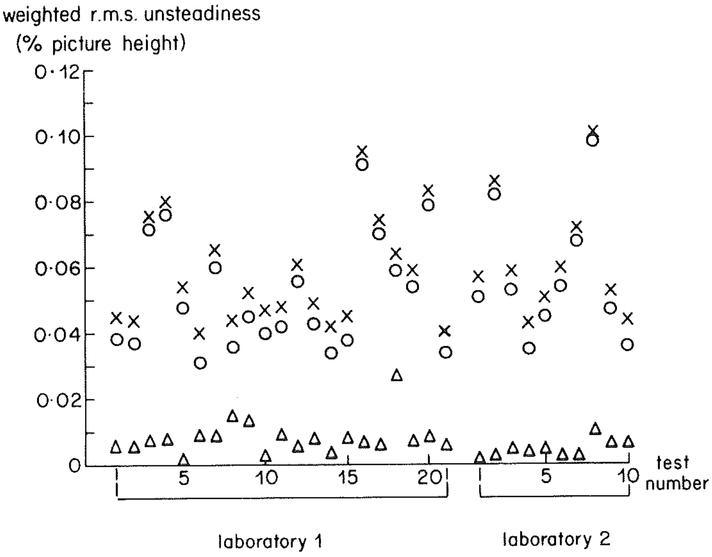

Fig. 6 - Vertical unsteadiness of printer and positive stock

○ Printer + positive stock

× Total (camera + negative + printer + positive + telecine)

△ 40 frame period component

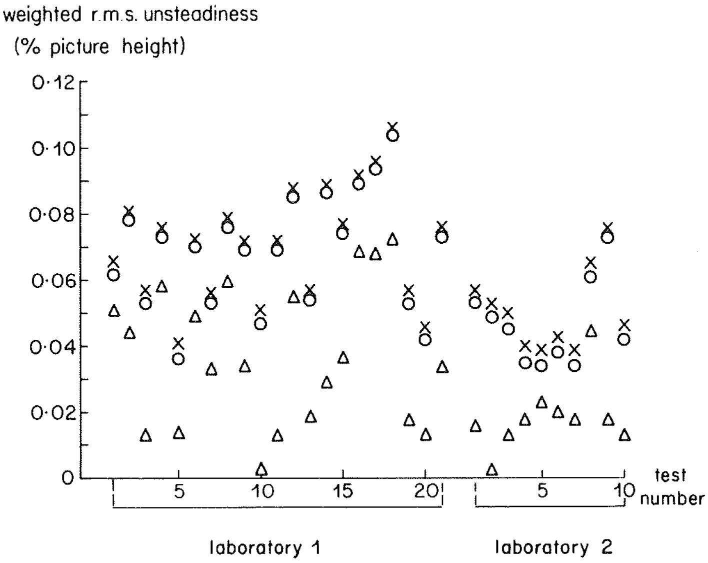

Fig. 7 - Horizontal unsteadiness of printer and positive stock

○ Printer + positive stock

× Total (camera + negative + printer + positive + telecine)

△ 40 frame period component

In the case of horizontal steadiness, shown in Fig. 7, there is a similar spread in results with minimum and maximum contributions from the printer and positive stock of 0·034% and 0·104% with a mean value of 0·061%. Again this is very significantly greater than the vector sum of horizontal and vertical unsteadiness of all the other items taken together (see Section 5.5). The 40 frame period component has again been separated from the total and its weighted r.m.s. contribution plotted separately. It will be seen that this is a variable component varying from almost zero to 0·072%. It is significant that this particular type of printer has 40 teeth on the printer drum and that some disturbance of the relative lateral position between the positive and negative must sometimes occur which is related to each rotation of the printer drum. The cause of this periodic disturbance is not known but is thought to be a function of the lateral bias provided by the feed rollers which maintain the film against the sides of the printer drum teeth. This bias probably varies from one stock batch to another with the tendency for the positive or negative film to twist and warp between the feed rollers and the printer drum.

A limited number of tests were made by printing a length of negative of known steadiness using a combination of printers and print stock. Four tests were made with printing machines using the same print stock at the same printing speed, and then, using a single machine, two further batches of print stock were compared at both slow and normal printing speeds (60 ft/min and 180 ft/min respectively). Table 10 shows the results of the tests on four machines using a single batch of print stock. The steadiness quoted is a total figure as in the previous tests.

TABLE 10

Printer Steadiness % Picture Height

Printer No.	Vertical (weighted r.m.s.)	Horizontal (weighted r.m.s.)	Peak-to-peak Horizontal 40 Frame Component
1	0·059	0·079	0·081
2	0·045	0·072	0·115
3	0·046	0·042	0·002
4	0·046	0·064	0·082

The vertical steadiness did not vary a great deal from machine to machine and represents a result close to the mean value of the results shown in Fig. 6. The horizontal unsteadiness, however, varied a great deal, particularly the 40 frame component which varied from almost zero in the case of Machine No. 3 to 0·115% peak-to-peak in the case of Machine No. 2.

The tests carried out with a single printer with three different print stocks at two different printer speeds were inconclusive due to the limited number of tests. However, the results showed that horizontal steadiness, in particular, was dependent on all three variables, i.e. machine, print stock and speed. In order to investigate further this dependence on three variables an extensive series of tests would be required, in which two variables were strictly controlled while determining the effect of the third. The scope of the present investigation did not permit an examination of this magnitude to be carried out.

6. Conclusions

The presentation of film by means of television imposes particularly heavy demands on many aspects of performance which have until recently been considered adequate, at least for optical projection. These demands arise since the performance of film is constantly open to direct comparison with the performance of television cameras.

This report has considered one aspect only, that of image steadiness from 16 mm film, which cannot be considered adequate when compared with the performance of a television camera.

In order to achieve a degree of image steadiness which may be judged acceptable it has been found that it is necessary to use a high-grade film camera employing register-pin location of the vertical film-position; edge guidance is satisfactory in the horizontal direction. The accuracy of film perforation has been found to be just adequate and better than the specification implies. Additions to the specification covering short term variations in dimensions have been proposed.

The one type of telecine machine considered has been found to be capable of excellent steadiness in its own right. Even better vertical steadiness could, however, be obtained if a standard position for camera register pins and telecine claws or sprockets could be agreed, so that the camera and telecine would both locate the film position by reference to the same sprocket hole, in relation to the image being exposed or scanned. Agreement to a standard position would then ease the film perforation accuracy required and, at the same time, improve vertical steadiness.

It has been assumed, so far, that camera-original film (either negative or reversal) is to be used in the telecine machine, and under these circumstances the impairment to steadiness, judged for a still scene, will usually be rated grade 3½ on the EBU impairment scale. This may be considered a just acceptable result, but there is no tolerance left for the occasions on which one item of the chain is below average performance.

The use of duplicate film (either a positive print or a reversal duplicate) made on a continuous printer will almost always result in serious unsteadiness. The average printer performance is such that it introduces more unsteadiness than the rest of the system (i.e. camera, film and telecine) added together. At the time of writing there is no immediate solution to the problem of unsteadiness introduced by high-speed printers.

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